SCANNING-BASED DETECTION OF IONIZING RADIATION FOR TOMOSYNTHESIS

FIELD OF THE INVENTION

The invention relates generally to scanning-based apparatuses and methods for obtaining tomosynthesis data for examination of an object.

BACKGROUND OF THE INVENTION AND RELATED ART

An X-ray medical diagnostic method such as mammography is a low-dose procedure that creates one or more images of a part of a patient such as a breast thereof, which is to be examined, e.g. for detection of early stages of cancer.

The mammography diagnostic procedure generally includes obtaining two images of each of the patient's breasts, one from above and one from the side. A physician or radiologist then reviews the images of the breast, i.e., mammograms, to identify any breast cancer.

While this procedure is one of the best methods of detecting early forms of breast cancer, it is still possible for the detection of breast cancer to be missed by a physician or radiologist reviewing the mammograms. For example, breast cancer may be missed by being obscured by radiographically dense, fibroglandular breast tissue.

Tomosynthesis imaging, in which a plurality of images is acquired at different angles, has been studied in an effort to detect early forms of breast cancer. By combining the plurality of images, it is possible to reconstruct any plane in the breast being imaged that is parallel to the detector. The higher number of images is utilized, the better image quality in the reconstructed tomosynthesis images is obtained.

Further, various line detectors for detecting ionizing radiation are known in the art. While such detectors provide for instantaneous one-dimensional imaging, two-dimensional imaging can only be performed by means of scanning the line detector, and optionally the radiation source, in a direction traverse to the one-dimensional detector array. To use such a detector in tomosynthesis, wherein a plurality of images has to be acquired at different angles would be very time consuming.

SUMMARY OF THE INVENTION

A main object of the invention is therefore to provide a scanning-based apparatus and a method, respectively, for obtaining tomosynthesis data of an object at a higher speed than what is obtainable by using scanning-based apparatuses and methods of the prior art.

In this respect there is a particular object to provide such an apparatus and such a method, which are capable of instantaneously recording, by means multiple one-dimensional detectors, multiple one-dimensional images of the object, and, by means of scanning, multiple two-dimensional images of the object, where each of the one-dimensional images of the object is recorded at a different angle.

A further object of the invention is to provide such an apparatus and such a method, which are capable of recording, by means of scanning a number of one-dimensional detectors over the object, a number of two-dimensional images of the object, where each of the two-dimensional images of the object is recorded at a different angle, and where the number of the two-dimensional images is higher than the number of one-dimensional detectors.

A still further object of the invention is to provide such an apparatus and such a method, which are uncomplicated and can produce high-quality two-dimensional tomosynthesis images with high spatial resolution, high signal-to-noise ratio, high dynamic range, high image contrast, and low noise from overlaying tissue.

A yet further object of the invention is to provide such an apparatus and such a method, which are reliable, accurate, and inexpensive.

These objects, among others, are attained by apparatuses and methods as claimed in the appended claims.

The inventors have found that by providing a divergent radiation source emitting radiation centered around an axis of symmetry, and a radiation detector comprising a stack of line detectors, each being directed towards the divergent radiation source to allow a ray bundle of the radiation that propagates in a respective one of a plurality of different angles to enter the line detector after having been transmitted through an object to be examined, and moving the radiation source and the radiation detector relative the object linearly in a direction orthogonal to the axis of symmetry, while each of the line detectors records line images of radiation as transmitted through the object in a respective one of the different angles, a plurality of two-dimensional images can be formed, where each two-dimensional image is formed from a plurality of line images as recorded by a single one of the line detectors.

Thus, a plurality of two-dimensional images at different angles are produced in a single scan, which reduces the

detection time by a factor corresponding to the number of two-dimensional images produced.

Preferably, a device is provided for rotating the radiation detector around an axis of rotation being orthogonal to the axis of symmetry, wherein the line detectors, after the rotation, are each directed towards the divergent radiation source to allow a ray bundle of the radiation that propagates in a respective one of a further plurality of different angles to enter the line detector, and the device for moving is further arranged to repeat the linear movement of the divergent radiation source and the radiation detector relative the object, while each of the line detectors is adapted to record a further plurality of line images of radiation as transmitted through the object in a respective one of the further plurality of different angles.

The data from the apparatus is excellent to be used in tomosynthesis or laminographic imaging.

The line detectors uses are preferably, but not exclusively, gaseous-based parallel plate detectors. Other line detectors that may be used include, scintillator-based arrays, CCD arrays, TFT- and CMOS-based detectors, liquid detectors, and diode arrays, e.g. PIN-diode arrays with edge-on, near edge-on or perpendicular incidence of X-rays. A collimator structure may be arranged in front of the detectors to partly reject scattered X-rays.

Further characteristics of the invention, and advantages thereof, will be evident from the detailed description of preferred embodiments of the present invention given hereinafter and the accompanying Figs. 1-4, which are given by

way of illustration only, and thus are not limitative of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 illustrates schematically, in a top view, an apparatus for obtaining tomosynthesis data for x-ray examination of an object according to a preferred embodiment of the present invention.

Figs. 2a-c illustrate each schematically, in a top view, a particular X-ray bundle as it traverses the examination object during a first scanning movement by the apparatus of Fig. 1.

Figs. 3a-c illustrate each schematically, in a top view, a particular X-ray bundle as it traverses the examination object during a second scanning movement by the apparatus of Fig. 1.

Fig. 4 illustrates schematically a cross-sectional view of a line detector of Fig. 1 as taken along the line I-I.

DESCRIPTION OF PREFERRED EMBODIMENTS

The apparatus of Fig. 1 comprises a divergent X-ray source 1, which produces X-rays 2 centered around an axis of symmetry 3 (parallel with the z axis), a collimator 4, a radiation detector 6, and a device 7 for rigidly connecting the X-ray source 1, the collimator 4, and the radiation detector 6 to each other and moving the X-ray source 1, the collimator 4, and the radiation detector 6 essentially linearly in direction 8 (typically parallel with the x axis) essentially orthogonal to the axis of symmetry 3 to scan an object 5, which is to be examined.

The radiation detector 6 comprises a stack of line detectors 6a, each being directed towards the divergent radiation source

1 to allow a respective ray bundle b1, …, b_n, …, b_N of the radiation 2 that propagates in a respective one of a plurality of different angles α_1, …, α_n, …, α_N with respect to the front surface of the radiation detector 6 to enter the respective line detector 6a. The line detectors 6a are extending in the y direction to record line images extending in the y direction.

The collimator 4 may be a thin foil of e.g. tungsten with narrow radiation transparent slits etched away, the number of which corresponds to the number of line detectors 6a of the radiation detector 6. The slits are aligned with the line detectors 6a so that X-rays passing through the slits of the collimator 4 will reach the detector units 6a, i.e. as the respective ray bundles b_1, …, b_n, …, b_N. The collimator 4, which is optional, prevents radiation, which is not directed directly towards the line detectors 6a, from impinging on the object 5, thereby reducing the radiation dose to the object. This is advantageous in all applications where the object is a human or an animal, or parts thereof.

During scanning the device 7 moves the radiation source 1, the collimator 4, and the radiation detector 6 relative the object 5 in a linear manner parallel with the front of the radiation detector as being indicated by arrow 8, while each of the line detectors 6a records a plurality of line images of radiation as transmitted through the object 5 in a respective one of the different angles α_1, …, α_n, …, α_N.

The scanning of the object 5 is preferably performed a length, which is sufficiently large so that *each one* of the line detectors 6a can be scanned across the entire object of interest to obtain, for each of the line detectors 6a, a two-dimensional image of radiation as transmitted through the

object 5 in a respective one of the different angles α_1, …, α_n, …, α_N.

In Figs. 2a-c three different X-ray bundles b_1, b_n, and b_N are schematically illustrated as they traverse the examination object 5 during scanning by the apparatus of Fig. 1. Reference numeral 9 indicates a plane parallel with the x axis, which coincides with the scanning direction 8 and with the front of the radiation detector 2.

As can be seen in Figs. 2a-c each line detector/X-ray bundle pair produces a complete two-dimensional image at a distinct one of the different angles. Fig. 2a illustrates the formation of a two-dimensional image of radiation transmitted through the object at an angle α_1, Fig. 2b illustrates the formation of a two-dimensional image of radiation transmitted through the same object, but at an angle α_n, and Fig. 2c illustrates the formation of a similar two-dimensional image, but at an angle α_N.

Preferably, the different angles are distributed over an angular range $\alpha_N-\alpha_1$ of at least 5°, preferably at least 10°, and most preferably at least 15° depending on the application or kind of examination in order to obtain high-quality tomosynthesis data for examination of the object. The number of line detectors 6a in the stack of line detectors is at least 3, preferably at least 10, and most preferably at least 25 depending on the number of images recorded at different angles, which is required during the examination.

The scanning step, in Figs. 2a-c denoted by sl, depends on the spatial resolution of the two-dimensional images formed from the one-dimensional recordings. Typically, the scanning step sl can

be about 10-500 microns, and the individual detecting elements of each of the line detectors can be of similar size.

Advantageously, the device 7 for performing the scanning movement, or other device (not illustrated), is capable of rotating the radiation source 1, the collimator 4, and the radiation detector 6 an angle Δ around an axis of rotation passing e.g. through the radiation source 1 or other point, and being orthogonal to the axis of symmetry 3, and preferably parallel with the y axis. The angle Δ is preferably smaller than the difference between two one adjacent ones of the different angles $\alpha_1, \ldots, \alpha_n, \ldots, \alpha_N$.

The radiation source 1 may, however, be kept still during the rotation if the line detectors 6a, after the rotation, are still within the solid angle of radiation as emitted by the radiation source 1.

The device 7 for moving then repeats the linear movement of the radiation source 1, the collimator 4, and the radiation detector 6 relative the object 5 in a second scan, while each of the line detectors records further multiple line images of radiation as transmitted through the object 5 in a respective one of the further different angles $\alpha_1+\Delta, \ldots, \alpha_n+\Delta, \ldots, \alpha_N+\Delta$.

In Figs. 3a-c three different X-ray bundles b_1, b_n, and b_N are schematically illustrated as they traverse the examination object 5 during the second scanning by the apparatus of Fig. 1. Reference numeral 9 indicates as in Fig. 2 a plane parallel with the x axis, which here slightly deviates from the scanning direction 8 and from the front of the radiation detector 2 due to the rotation.

As can be seen in Figs. 3a-c each line detector/X-ray bundle pair produces a complete two-dimensional image at a distinct one of the different angles. Fig. 3a illustrates the formation of a two-dimensional image of radiation transmitted through the object at an angle $\alpha_1+\Delta$, Fig. 3b illustrates the formation of a two-dimensional image of radiation transmitted through the same object, but at an angle $\alpha_n+\Delta$, and Fig. 3c illustrates the formation of a similar two-dimensional image, but at an angle $\alpha_N+\Delta$.

Thus, two linear scans with a slight rotation therein between provide for the formation of 2N two-dimensional images at the different angles α_1, $\alpha_1+\Delta$, ..., α_n, $\alpha_n+\Delta$, ..., α_N, $\alpha_N+\Delta$. Similarly, the rotation and linear scanning may be repeated P times to obtain PxN two-dimensional images. In such a manner a large number of images at different angles may be obtained by using a limited number of line detectors. Hereby, a low cost radiation detector can be provided to the cost of a prolonged scanning and examination time. The total radiation dose to the object 5 during the examination has, however, not necessarily to be increased.

Alternatively, or additionally, the rotation may be performed around an axis of rotation, which is parallel with the x axis, between linear scans of the above-described kind.

The more images at different angles are provided, the smaller is the noise from overlaying objects in the reconstructed tomosynthesis image.

In another embodiment of the invention two or more linear scans as disclosed above are performed, and between each of the linear scans a rotation of the above-kind is performed, but where the

rotation is larger than the angle range $\alpha_N-\alpha_1$ of the different angles $\alpha_1, \ldots, \alpha_n, \ldots, \alpha_N$.

In such a manner the obtained effective opening angle of the radiation detector 6 is made larger (two times for two linear scans) without that the radiation detector 6 has to be made larger, or include more line detectors 6a. If two linear scans are performed with a rotation of the radiation source 1, the collimator 4, and the radiation detector 6 an angle $\alpha_N-\alpha_1+\gamma$ therein between, 2N two-dimensional images can be recorded at the different angles $\alpha_1, \ldots, \alpha_n, \ldots, \alpha_N, \alpha_1+\alpha_N-\alpha_1+\gamma, \ldots, \alpha_n+\alpha_N-\alpha_1+\gamma, \ldots, \alpha_N+\alpha_N-\alpha_1+\gamma$ or angles $\alpha_1, \ldots, \alpha_n, \ldots, \alpha_N, \alpha_N+\gamma, \ldots, \alpha_n+\alpha_N-\alpha_1+\gamma, \ldots, 2\alpha_N-\alpha_1+\gamma$.

It shall be noted that the present invention is applicable to any kind of examination employing tomosynthesis or laminographic imaging, including e.g. mammography examination and other soft tissue examinations.

A preferred line detector for use in the present invention is a gaseous-based parallel plate detector, preferably provided with an electron avalanche amplifier. Such a gaseous-based parallel plate detector is an ionization detector, wherein electrons freed as a result of ionization by ionizing radiation are accelerated in a direction essentially perpendicular to the direction of the radiation.

A cross-sectional view of a line detector of Fig. 1 as taken along the line I-I is schematically illustrated in Fig. 4.

The line detector comprises a window 30 for entry of a ray bundle, and a row of elongated individual conductive detector elements or strips 27 arranged on a dielectric substrate 28. Preferably, the elements or strips 27, which each is capable of

separately detecting incident radiation photons, also constitute an anode of the line detector to attract the electrons released during ionization of the ionizable gas in the line detector. Preferably, the dielectric substrate 28 and the window 30 define, together with sidewalls 29, 31, 32 and a non-illustrated dielectric cathode substrate, a gas-tight confinement capable of being filled with the ionizable gas. Alternatively, the line detector is arranged within an external gas-tight casing (not illustrated).

Note that the individual conductive detector/anode elements 27 are arranged side by side in a row parallel with the y direction, and define a respective angle $\beta_1, \ldots, \beta_m, \ldots, \beta_M$ with respect to the xz plane so that all the detector/anode elements 27 point towards the X-ray source 1 to avoid any parallax errors caused by the divergent radiation. As a result different detector/anode elements 27 detect *different* angular portions $\beta_1, \ldots, \beta_m, \ldots, \beta_M$ of the ray bundle entered into the line detector.

For further details regarding such kind of gaseous-based line detectors for use in the present invention, reference is made to the following U.S. Patents by Tom Francke et al. and assigned to XCounter AB of Sweden, which patents are hereby incorporated by reference: Nos. 6,546,070; 6,522,722; 6,518,578; 6,118,125; 6,373,065; 6,337,482; 6,385,282; 6,414,317; 6,476,397; and 6,477,223.

It shall particularly be pointed out that such kind of detector is very efficient in preventing Compton scattered radiation from being detected. This property is of outermost importance to obtain high-quality tomosynthesis data.

The distance between the parallel plates, i.e. electrodes, of the line detector may be below about 2 mm, preferably below about 1 mm, more preferably below about 0.5 mm, and most preferably between about 0.1 mm and 0.5 mm. XCounter AB has recently begun to verify the Compton scattering rejection characteristics of the line detector experimentally and good contrast has been observed using a wide X-ray spectrum of high energy X-rays, at which conditions a conventional detector system would not be capable to see any structure at all. It is believed that the above-depicted gaseous-based line detector discriminates more than 99% of the scattered photons; and by proper design it is assumed that about 99.9% or more of the scattered photons can be prevented from being detected.

It shall, nevertheless, be realized that any other type of detector may be used in the present invention. Such line detectors include scintillator-based arrays, CCD arrays, TFT- and CMOS-based detectors, liquid detectors, and solid-state detectors such as one-dimensional PIN-diode arrays with edge-on, near edge-on or perpendicular incidence of X-rays, possibly with a collimator structure in front to partly reject scattered X-rays.

It shall further be noted that that the device 7 for rigidly connecting the X-ray source 1, the collimator 4, and the radiation detector 6 may be exchanged for separate devices (not illustrated) for the X-ray source 1, the collimator 4, and the radiation detector 6, which may be controlled electronically to obtain synchronous movements of the separate devices to obtain similar scanning movement. Yet alternatively, the apparatus of Fig. 1 can be modified so the object 5 is moved during scanning, while the radiation source

1, the collimator 4, and the radiation detector 6 are kept at rest.

It shall still further be noted that instead of performing linear scans for each rotation, the linear scanning may be performed stepwise, and at each such linear scanning step measurements are made for different rotations. The result is identical, but the measurements are performed in different order. It shall be noted that the present patent document covers both these measurements.

It shall yet further be noted that in an alternative embodiment of the present invention the linear scanning is performed in the y direction and the rotation between the linear scannings is performed around an axis parallel with the x axis. This calls for a very short distance between the line detectors in the stack since one detector strip from each line detector provides the instantaneous one-dimensional image. One complete scan in the y direction involves that each of the detector strips of each of the line detectors is moved across the complete object. The strips of the plurality of line detectors, which are inclined to the xz plane with the angle β_1, record, during the scan, one two-dimensional image, the adjacent strips record another two-dimensional image at a different angle, etc. After the first scan the detector is rotated an angle $+\Delta$ around an axis parallel with the x axis. During the second scan, the strips of the plurality of line detectors are inclined to the xz plane with $\beta_1+\Delta$, ..., $\beta_m+\Delta$, ..., $\beta_M+\Delta$. Thus, two linear scans with a slight rotation therein between provide for the formation of 2M two-dimensional images at the different angles β_1, $\beta_1+\Delta$, ..., β_m, $\beta_m+\Delta$, ..., β_M, $\beta_M+\Delta$. Similarly, the rotation and linear scanning may be repeated P times to obtain PxM two-dimensional images.